

Building an 80 metre magnetic loop antenna for your attic

Jim Tregellas VK5JST

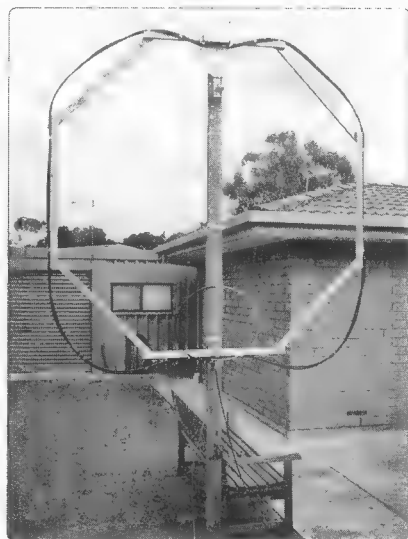


Photo 1: Testing the loop on a temporary frame.

Part 1

Short of space in your suburban backyard or retirement village? Want a good small antenna for 80 metres? Properly built and sited, this design can perform as well, or better than G5RVs, half wave dipoles, and off-centre fed dipoles, and even better, delivers this performance at the breathtaking height of two metres above ground. And if you are prepared to substitute time for dollars, then it is cheap too. Theory and details are given about how to build one to fit your space.

The Theory

A magnetic loop antenna typically consists of a circle (or a similar shape with a large central area) of low resistance conductor tuned to parallel resonance with a capacitor. Energy from the transmitter can be coupled into the loop using a variety of techniques and these include the gamma match, an iron dust or ferrite cored toroidal transformer, and a shielded or unshielded single turn air coupled driver coil. A loop perimeter between 0.1 and

0.2 wavelengths gives good efficiency.

If this loop is mounted so that the plane of the circle is at right angles to the ground, the result is a figure eight radiation pattern having two sharp nulls at either end of the axis of the circle. These nulls can be very useful in removing local interference. For best radiation pattern the loop should be mounted with the maximum voltage points (at the capacitor) uppermost and the current maximum which is opposite to the capacitor at the bottom.

The loop has a very low radiation angle and only has to be mounted high enough to prevent the strong magnetic field it produces from inducing significant losses in the ground. At 80 metres this means that there shall be at least 1.5 metres between the bottom of the loop and ground, and also that there is very little extra advantage to be had by mounting it much higher. Of course the loop also needs to be mounted away from metallic objects such as fences, plumbing, garage doors, or the like which will induce currents that can cause unacceptable losses and distorted radiation patterns.

The advantages gained from having such a low radiation angle at a low height cannot be overstated and in this respect a loop is like a vertical. Unlike the vertical however, the figure 8 pattern gives it more gain in some directions and it is less noisy. The 10 metre height restriction placed by city councils on the mounting of antennas means that at 80 metres, wire antennas like the G5RV and half wave dipole can only be legally mounted at a maximum of $1/8^{\text{th}}$ of a wave length above ground and not the desired minimum of $1/4$ wave length. This low mounting height results in an antenna that is good for local contacts but poor for DX because most of the energy is radiated almost vertically.

So in summary, the magnetic loop has a very small footprint, is relatively quiet, and is excellent for DX. With only a little extra trouble it can be mounted on a simple rotator that only needs to move through 90 degrees to give continuous coverage in all directions.

For this performance, there is a price. The antenna is really just a large parallel resonant LC circuit which only transmits efficiently when it has VERY low losses. Another way of saying this is that the quality factor of the tuned circuit (Q) must be very high, and typical figures for Q are around 1000 (0.1 % losses). Arrggghhh.....

At 3.5 MHz, a Q figure of 1000 means that the antenna has a bandwidth of just 3.5 kHz, which in turn means that the antenna will need continual retuning to cover the ham band from 3.5 -3.7 MHz. So we need a really good method of remotely tuning the antenna, and some simple and reliable method of indicating the frequency to which it is currently tuned.

The losses with which we are so concerned occur in two areas. First there is the loss in the main conductor of the loop caused by 'skin' effect. At low frequencies, current flow occurs uniformly throughout the cross section of a conductor, but as the frequency rises, the rapidly expanding and contracting AC magnetic field which surrounds the conductor forces the current carriers to near the surface. As the current carriers now only move in a much smaller area of the conductor, the apparent resistance rises too. We can lower these losses in a number of ways. First we can use a conductor that is simply bigger (greater surface area). Next we make sure that the conductor surface is smooth and continuous so that current carrier

flow is unimpeded. And last we can electroplate the conductor surface with a material with a very low resistance such as silver. There is another way too, and this is to multiply the surface area available by using a number of smaller insulated conductors in parallel. Insulation is most important because it is this that allows all of the surface area of each of the paralleled wires to be used. Without insulation, a group of wires in contact will simply act like a large single conductor of the same outside diameter as the group, because skin effect forces the current to the outside perimeter of all of the wires.

This idea of multiplying the available surface area by using many small diameter insulated wires in parallel is the basis for the production of 'Litz' wire (short for the German 'Litzendraht') which is used to wind low loss RF coils for items such as the ferrite rod antennas found in transistor radios. It allows us to use the insulated outer sheaths of several pieces of RG8 or RG213 in parallel to make up a single loop conductor with a much larger effective diameter. Being a woven structure, the outer shield of this type of coaxial cable is very rough and in this application has unacceptable RF losses. This is due to skin effect which keeps the current on the outside of the sheath, forcing it to hop from conductor to conductor as one conductor disappears under another in the weave. Each hop involves passing through a resistance where the two conductors contact each other. But with several sheaths in parallel, the losses are much reduced and we have an acceptable engineering compromise. We could use smooth copper water pipe but this is very rigid and difficult to handle. Another alternative is the smooth outer sheath of LDF4-50 or even LDF5-50 semi rigid coax. This cable is expensive and not easy to come by second-hand but of all the possible loop conductor materials it is probably the best compromise for the amateur. Like ordinary coaxial cable, it is flexible. This is an important advantage, because it allows the loop conductors to be

easily placed into the cavity of a non metallic roof where they will form an efficient invisible antenna out of the weather. Such antennas are largely immune to carping comments from wives, neighbours, and governing bodies like councils and those who oversee flats and retirement villages. They are almost free from maintenance too.

The second area of loss is in the capacitor. There are two parts to this, resistive losses and dielectric losses. For efficient operation, a typical loop must have a Q of around 1000, and if we assume that there are equal losses in the loop conductors and capacitor (an unrealistic assumption- see below) then the capacitor must have a minimum Q of around 2000. With a power input to the loop of say 100 watts, we are going to find circulating currents around the loop of maybe 35 amps and peak voltages across the capacitor of around 5000 volts. Qs of greater than 400 are very difficult to achieve, let alone 2000, and so attention must be paid to the smallest details.

Dealing with the resistive losses first, long experience by many loop constructors has shown that normal variable capacitors are useless for loop construction. The sliding mechanical contacts provided to allow RF current to flow from the capacitor frame to the moving plates have losses that are too high to allow the very high Q necessary. In extreme cases, the amount of heat generated in these contacts by the very high currents circulating around the loop can cause physical damage. The result is a poor Q and a loop that is a very poor radiator.

There are really only two types of variable capacitor that are useful, and these are the vacuum variable and butterfly capacitor structures. Both of these exhibit very high Qs, achieved in different ways. In the butterfly capacitor, resistive losses are avoided by having the RF current enter and exit the capacitor via two sets of fixed plates, which are coupled together by a common set of moving plates. No sliding mechanical contacts, and in the best of these capacitors, all the plates in

each of the three sets are welded or soldered together. In the vacuum variable, contact to the moving plates is made via a cylindrical set of copper bellows, which concertina in and out allowing movement, while keeping the capacitor interior under high vacuum. Unhappily, tuning of a reasonable size loop at 3.5 MHz needs a capacitor of around 300 pF. The butterfly capacitor needs an interplate spacing of around 2.5 mm of air to withstand the 5000 volts of RF and consists of two 600 pF capacitors in series. It consequently ends up as unacceptably large AND expensive, while the vacuum variable capacitor is just plain VERY expensive. To keep costs down we need another solution.

The other set of losses in the capacitor occur in the dielectric. These losses are normally measured in terms of the dielectric dissipation factor D, which is the inverse of Q. So if we want a capacitor with a Q of 2000 or more, we have to find a dielectric with a D of 0.0005 or less. The dielectric should also have an extremely high breakdown voltage so that we can put the plates close together and keep the capacitor small. Air and vacuum are excellent dielectrics with near zero losses but finding anything else which is good enough for this extremely demanding application is very difficult to do. To the author's amazement, glass is very poor with a D of just 0.007 or a Q of around 160 and so is utterly useless. In fact there are only two other dielectrics which go close to requirements and both of these are modern plastics. High density polyethylene (HDPE) has a dissipation factor of around 0.0004 at 1 MHz, as does polypropylene (HDPP). Unfortunately these dissipation figures are marginal, because the capacitor really needs to have a Q of much greater than 2000, to compensate for the obviously larger resistive losses that will occur in the very long loop conductors. So if we wish to use plastics at all as a dielectric then we should only do so in a small part of the total capacitance to keep our overall losses down. I have replaced

an air spaced tuning capacitor with a capacitor made up from 16 short paralleled lengths of RG213 to keep the resistive losses way down. RG213 uses pure HDPE as its dielectric. The result of this exercise was a dramatic drop in performance. In short there are no quick and dirty fixes and much of the material published on the Internet about capacitors in particular, and loop construction in general, will produce results that are not worth having.

One other consideration affects the capacitor and this is the accuracy with which it must be set. To cover the 80 metre band, the frequency must change from 3.5 to 3.7 MHz. This is a 5.5%

frequency change, which requires a capacitance change of exactly double this figure to cause it (11%). A butterfly capacitor only moves through a total of 90 degrees of rotation, and so an 11% capacitance change occurs in about 10 degrees of rotation. If the antenna has a bandwidth of 3.5 kHz ($Q=1000$), then to get a good SWR we will probably want to tune it with an accuracy of better than 200 Hz. If 10 degrees of rotation causes a 200 kHz frequency shift, then a 200 Hz shift is caused by shaft movement of a whole one hundredth of a degree! Even if a vacuum variable capacitor is used which typically takes 30 shaft turns to go from minimum to maximum

capacitance, we still only need to move the shaft about one degree to get a 200 Hz shift. So a highly geared slow motion drive to the tuning capacitor becomes absolutely mandatory. It also makes sense to make up the tuning capacitance from a large fixed capacitor in parallel with a small variable unit so that this tuning problem is minimised. In turn this means a monoband antenna, but these loops are small enough to allow you to have an entire antenna farm in your roof cavity. A really efficient loop for 14 MHz is just one metre in diameter! More next month.....



Remembrance Day Contest

0800 UTC Saturday 13 August 2011 to 0759 UTC Sunday 14 August 2011

The RD Contest provides for amateurs in each state to obtain points for working other amateurs in Australia, PNG and New Guinea, and in so doing contributing points for his/her state – the overall aim of the contest being to see which state attains the top score in the contest.

The individual amateur can be presented with a certificate (as pictured) with their name, callsign, the category they entered, and total points scored.



The winning state will have their state's name embossed on the perpetual Trophy.

The Rules are available for download from the WIA Website:

http://www.wia.org.au/members/contests/irdcontest/documents/2011_RD_Rules.pdf

Peter Harding VK4OD



Coming Events

9-10 July

VK3 – GippsTech 2011 VHF/UHF and microwaves technical conference, Churchill.

16 July

VK3 – Gippsland Gate Radio & Electronics Club Hamfest, Cranbourne.

16 July

VK4 – Wide Bay Hamfest, Maryborough Electronics and Radio Group.

31 July

VK2 – Riverina Field Day, Albury Wodonga Amateur Radio Club Inc.

Building an 80 metre magnetic loop antenna for your attic

Jim Tregellas VK5JST



Photo 1: Testing the loop on a temporary frame.

Part 2

The practical antenna

I settled on a loop with a perimeter of 0.1 wavelengths or 8.3 metres (2.6 metres diameter) after a careful look at my attic. Some calculation (see the website of KI6GD for the file loopcalc.zip) with an assumed loop conductor diameter of 18 mm

(copper water pipe) showed that I would need a tuning capacitor of around 280 pF to tune the loop down to 3.5 MHz and this capacitor would have to withstand around 4000 volts and several tens of amps. If the loop was operating with the predicted 18 to 20% efficiency, it would exhibit a Q on transmit of about 880.

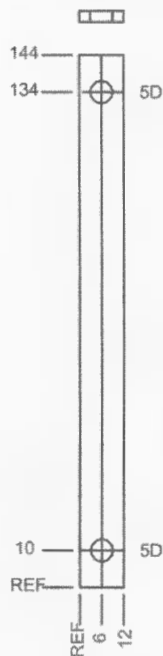
Next step was to price the

loop conductor. I went to my local plumbing supplier and priced 8.5 metres of 18 mm diameter copper pipe. The figure quoted caused a rapid rethink. I checked the price of LDF4-50 and it was the same as the water pipe. LDF5-50 was not even funny. So back to the drawing board. At this point I was anything but sure that an antenna with a calculated efficiency of 20% was even worth having, and so I wanted a cost free method to prove the concept. After looking around under some benches I found enough short lengths of RG213 to make up three parallel turns of conductor. This was equivalent to having a single turn of a conductor with a diameter of 27 mm - which would have higher than normal losses due to the rough surface of the coax outer sheaths. I also had several Jennings vacuum variable capacitors which would fit requirements, and using one of these I made up my first loop. The results were very encouraging. The loop Q was around 1100, which clearly demonstrated that the coax losses were not as bad as first thought. I then removed one strand of the RG213 and the loop Q dropped to 810. So far, so good.

The next step was to get rid of the very expensive vacuum variable capacitor and simultaneously make the tuning less critical. This took about two weeks of fooling about. What finally evolved was a fixed 240 pF air spaced capacitor with super low losses in parallel with a 50 pF trimmer capacitor to allow tuning across the band. This structure rivals the vacuum variable in performance. The trimmer uses HDPE as the dielectric which keeps it physically small. It is driven via a screw thread from a low power stepper motor, and because the trimmer is only a small part of the total capacitance and the screw thread is fine, tuning is easy.

28 **Amateur Radio** · August 2011

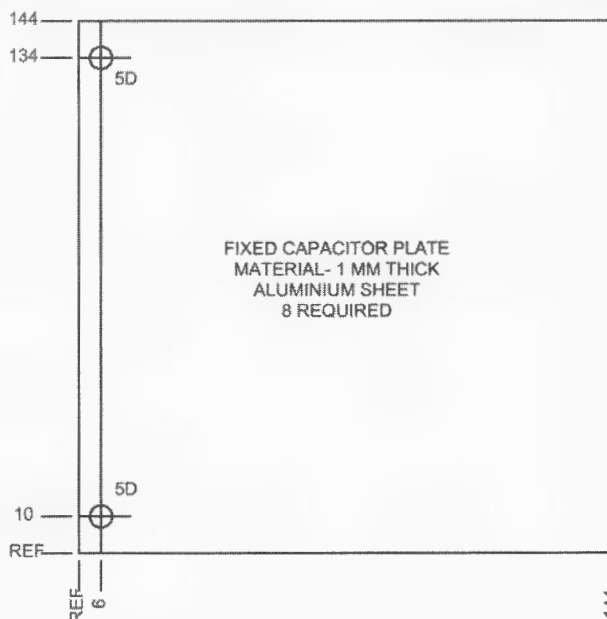
FIXED CAPACITOR
SPACER
MATERIAL- 12 X 3 MM
ALUMINIUM FLAT
2 REQUIRED



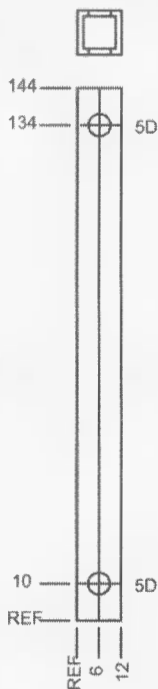
FIXED CAPACITOR
SCREW COLUMN
MATERIAL-
3/16 INCH BSW
THREADED ROD
4 REQUIRED



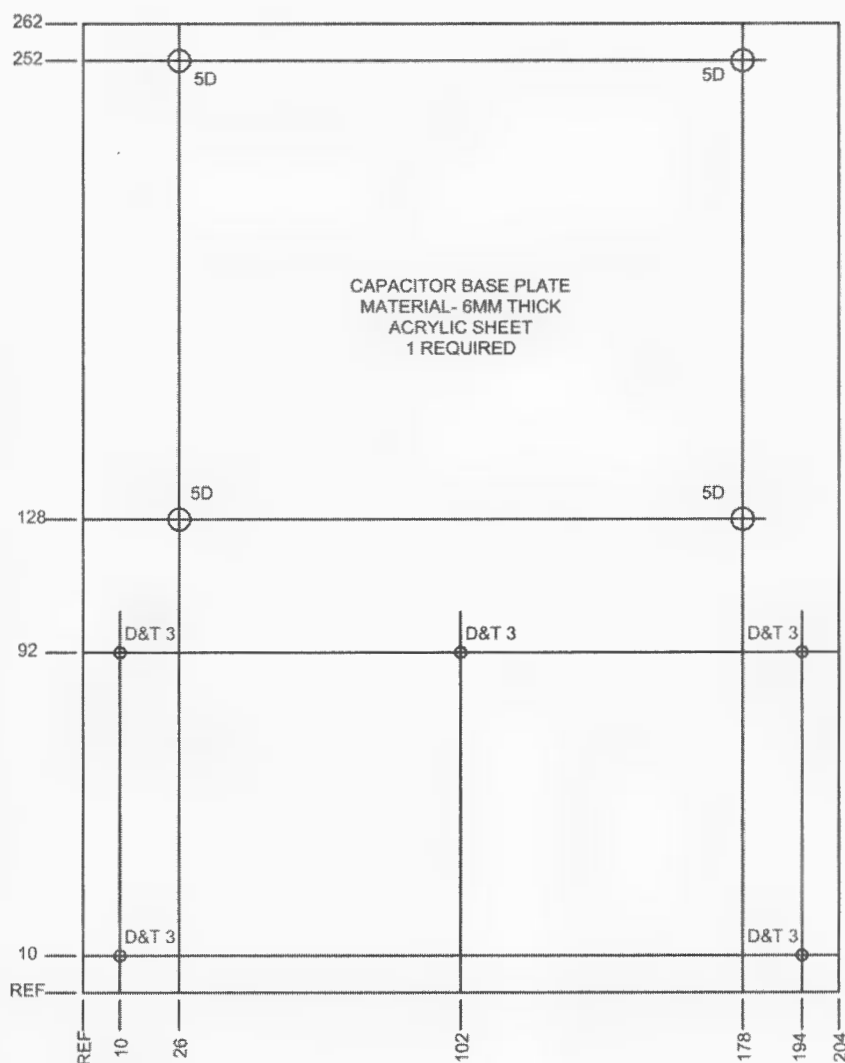
FIXED CAPACITOR PLATE
MATERIAL- 1 MM THICK
ALUMINIUM SHEET
8 REQUIRED



FIXED CAPACITOR
SPACER
MATERIAL- 12 MM
SQUARE ALUMINIUM
TUBE- 7 REQUIRED



CAPACITOR BASE PLATE
MATERIAL- 6MM THICK
ACRYLIC SHEET
1 REQUIRED



BASE PLATE AND FIXED CAPACITOR DETAILS

DRAWN VK5JST MAY 2010

Figure 2: The fixed capacitor.

It is a modified butterfly capacitor where the two fixed plates are positioned side by side on an acrylic backing sheet and a moving plate slides over the pair coupling them together. Finding the dielectric was not easy. After hunting around the local plastics suppliers, it became clear that the thinnest HDPE sheet they had was 3 mm thick. This is way too thick to make a trimmer capacitor of reasonable size. I nearly gave up at this point, but a shopping trip to Woolworths saved the day. There I found some kitchen cutting mats (Chef Craft Flexible Cutting Mats - pack of 4-305 x 380 mm - \$5) which were ideal, and even better, are a standard stock line. These mats are pure HDPE 0.8 mm thick. HDPE has a breakdown potential of 17 kV/mm minimum and so these mats can be used to make capacitors with 13,000 volt ratings (or 26000 volts in this case as there are two layers in series). HDPE has a dielectric constant of 2.2 but because one side of these mats is very finely patterned, the actual dielectric constant turns out at about 1.5 due to the small included layer of air. The trimmer ends up having two sets of plates with a working area of 72 x 80 mm spaced apart with 0.8 mm thick HDPE, making up two capacitors of around 100 pF maximum in series to form a 50 pF adjustable capacitor. The fixed plates are held in position side by side 20 mm apart with two of the retaining screws for the fixed plates. They are attached to the acrylic backing with standard double sided adhesive tape. Note that all brass plates in the variable capacitor must be very flat so that there are no significant air gaps in the assembly. The edges of all three plates must be carefully rounded and smoothed. The whole capacitor is held together with light spring pressure from springs on the shafts of five 25 mm long 3 mm diameter retaining screws. These screws pass through the top plate and dielectric separator to the backing plate and the springs bear down on the 6 mm thick top plate.

The fixed air spaced capacitor of around 240 pF is made with 1 mm thick aluminium plates spaced

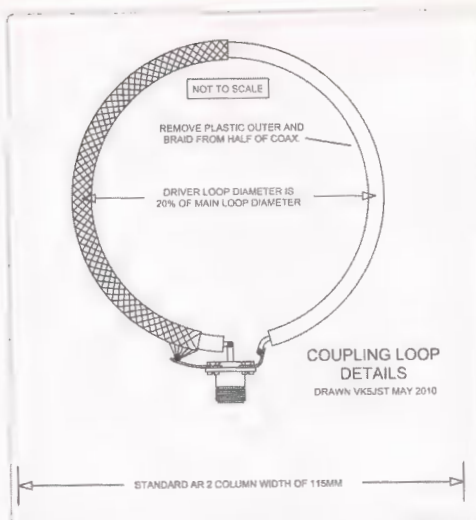


Figure 3: The coupling loop details.

apart using 12 mm square aluminium tube, giving a 5.5 mm interplate spacing. As air has a breakdown potential of around 3000 volts/mm this means that the fixed capacitor should work happily up to 11000 volts rms.

My final design is as follows. The loop has a circumference of 8.3 metres and is made of two parallel turns of RG213 or RG8 outer sheath (do not remove the plastic outer insulation). Slightly better alternatives are one turn of 18 mm copper water pipe, or LDF4-50, or LDF5-50 if you want to spend the money or have it handy. These conductors can be attached to your internal roof structure in any reasonable shape which has a large internal area. This could be a circle, an octagon, or a square/rectangle/triangle with very rounded corners. Note that the antenna becomes more efficient as the perfect circular shape is approached and as the perimeter is increased. With a perimeter of 8.3 metres, the efficiency is around 20%. Even an antenna this small can compete with and sometimes out perform the typical inefficient wire antenna mounted at 10 metres. If the perimeter can be increased to around 15 metres (0.2 wavelengths), the efficiency rises to some 60% and you will have a 'big signal' on 80 metres. If your loop perimeter is bigger than 8.3 metres then you must reduce the size of fixed and

variable capacitors. Plates are easily removed from the fixed capacitor to allow this (part plates can also be used) and the plate sizes of the trimmer capacitor are easy to scale down too.

Feeding the loop

There are a number of ways energy from the transmitter can be coupled into the main loop. These include transformer coupling, the gamma match, and single turn shielded and unshielded coupling loops of around 20% of the diameter of the main loop. I like the last two methods because they are simplest to make and adjust. A single turn coupling loop, half of which is covered with a Faraday shield to limit noise pickup, is easily made from a length of RG213 - refer Photo 1. When properly set up, the SWR of the antenna can be easily adjusted by flattening or stretching the circular shape of the coupling loop. An alternative technique is to slightly overlap the main and coupling loops.

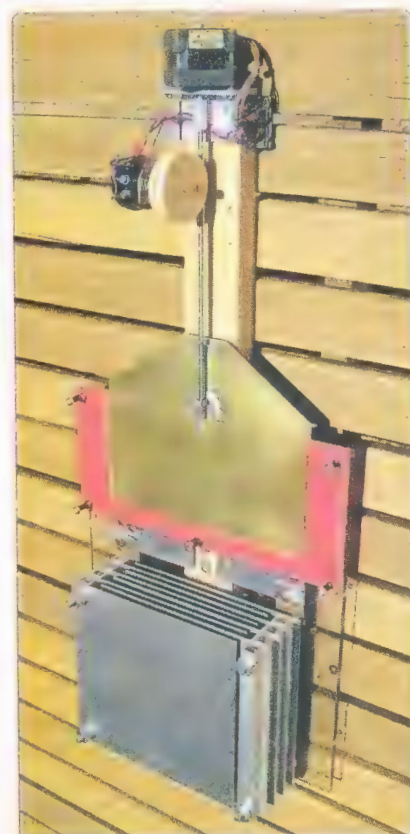


Photo 2: The tuning capacitor and feedback potentiometer assembly.

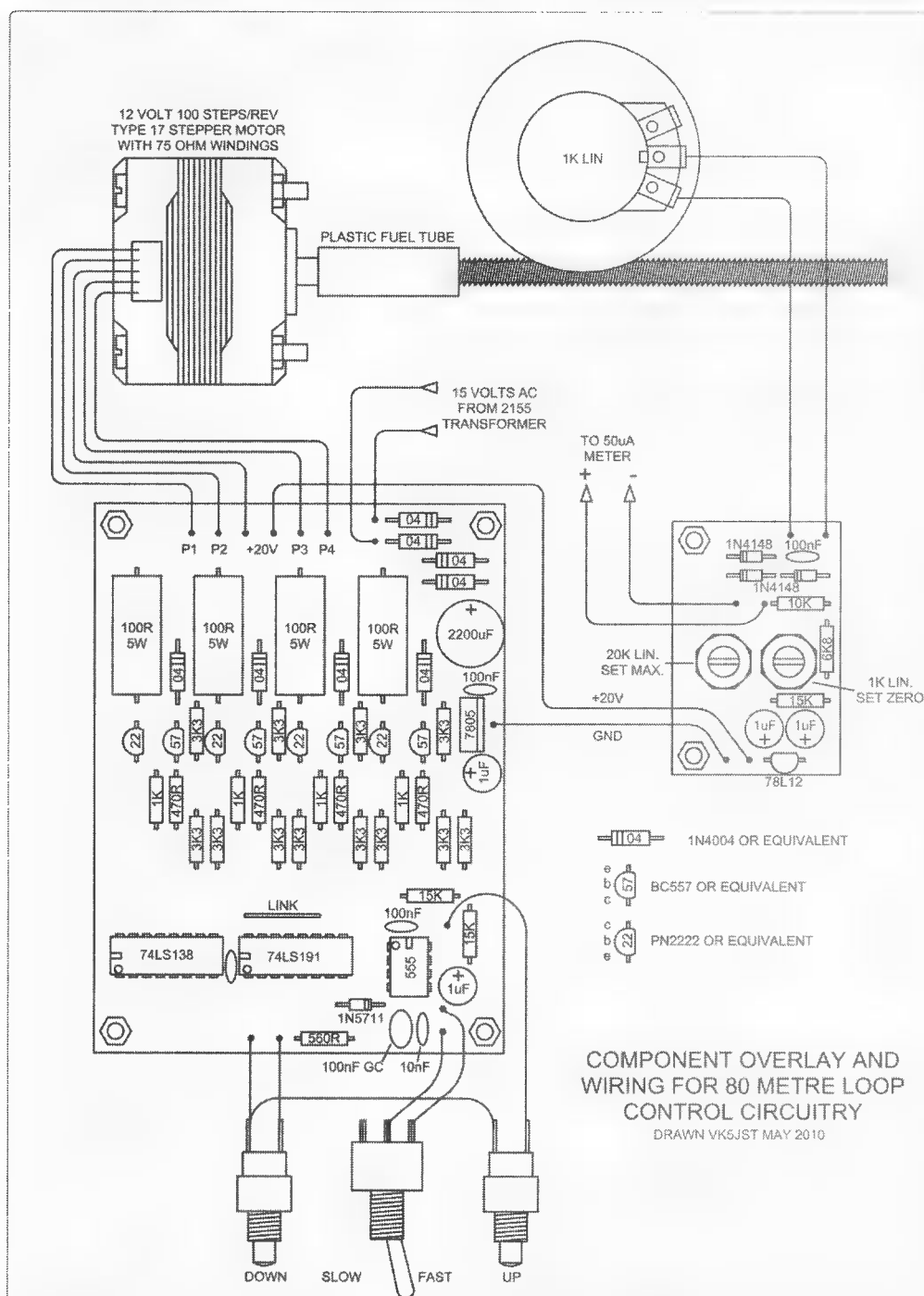


Figure 4: The component overlay and wiring for the loop control circuitry and hardware.

Getting an SWR under 1.1:1 is not difficult.

Tuning the loop

Loop tuning is done from a remote control unit which provides forward and reverse drive to a stepper motor at either a 27 Hz or 300 Hz rate (8 or 90 rpm). To tune across the band requires a capacitance variation

of around 31 pf. This corresponds with a 47 mm movement (out of a possible 80 mm) for the moving plate of the 50 pf trimmer capacitor. If we use a 3/16 inch BSW screw thread (24 TPI) to match the stepper motor shaft diameter and drive the capacitor, the stepper motor must move through about 50 turns or 5000 steps to cover the band. This

gives around 60 Hz per step which is more than fine enough to give excellent tuning. It also means that tuning right across the band will take around 17 seconds at the high step rate.

The stepper motor is a type 17 12 volt 75 ohm unit (or thereabouts) that is best obtained free from an old 5.25 inch floppy disc drive unit. The clock circuit is a two speed 555 circuit which drives a 74LS191 binary up down counter. The least two significant bits from this counter are decoded in a 74LS138 to provide a one out of four output on pins 12, 13, 14 and 15 of this chip. Each output is then OR connected to drivers connected to each motor phase to provide a two phase drive.

An indication of the frequency to which the loop is tuned is fed back to the operator on an analog meter. This meter is powered from a simple potentiometer coupled via worm wheel to the trimmer capacitor drive screw. Refer to Photo 3 showing how to make this worm wheel using a tap and a bench drill. Any soft material about 10 mm thick such as plastic, five ply, Bakelite or acrylic sheet can be used. A fly cutter is used to cut out a 38 mm diameter

disc of material. Place a drill through the central hole in the disc to use as an axle. On the edge of the disc grind a shallow semi circular trench by allowing the disc to spin against one corner of a rotating bench grinder wheel. This trench should be sufficiently deep to allow contact from two of the flutes on the tap, causing the disc to spin and cut a

LOOP ANTENNA CONTROL CIRCUITRY DRAWN VK5JST JAN. 2010

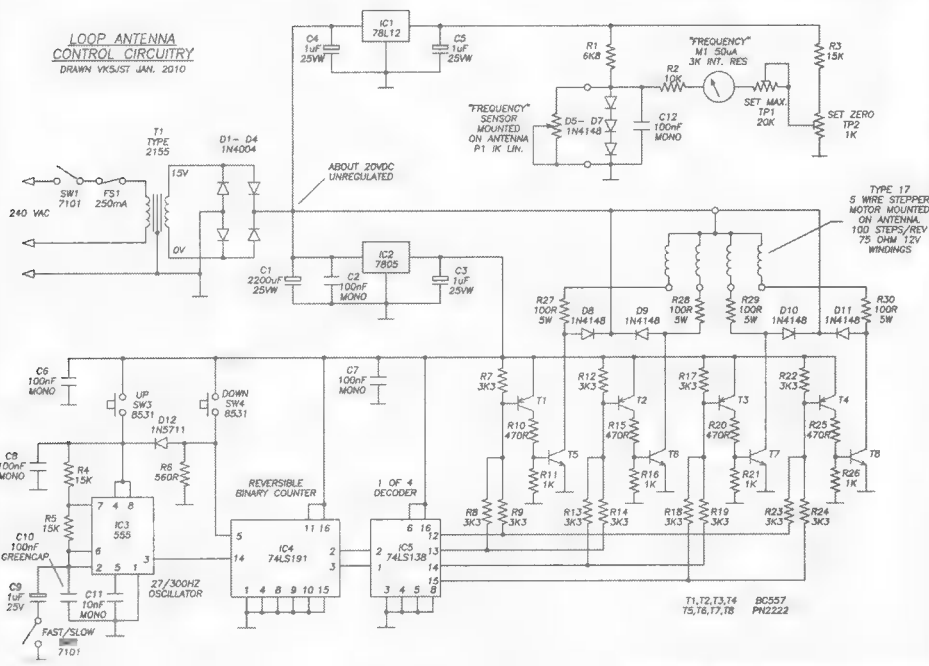


Figure 7: The copper pattern for the stepper control electronics.

thread from the moment it contacts the spinning tap in the drill. Make sure that the tap forces the worm wheel against the backing plate when cutting the thread! Clamp the backing plate to the drill table, and gently swing the drill table around the drill post to make cutting easy. If you use plastic, keep the tap cool

otherwise you will end up with no thread on the worm wheel, and a tap buried in melted plastic. I used a carbon pot with about 270 degrees of rotation and so I needed a worm wheel with about 75 teeth (75 revs from maximum to minimum capacitance) in around 240 degrees, or around 112 teeth

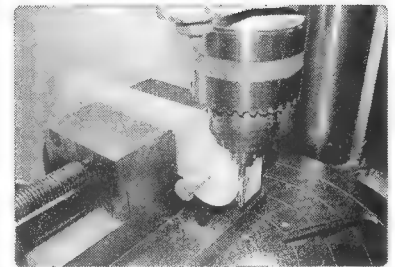


Photo 3: How to make a worm wheel in a drill press.

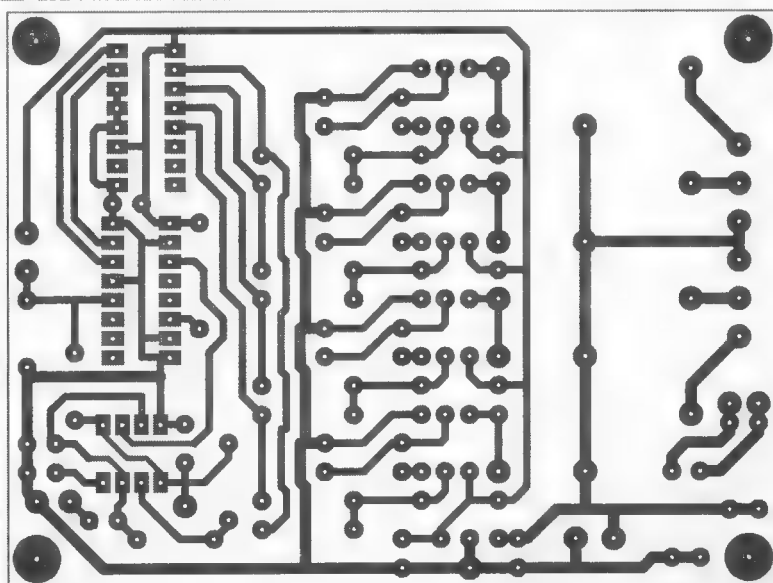
in 360 degrees. This gave a circumference of about 120 mm or a diameter of 38 mm. This worm wheel is fixed to the pot shaft with a blob of silicon sealant. The analog meter can be roughly calibrated in frequency terms using the two trimpots provided in the control unit.

And Finally.....

When you have mounted the antenna in your attic enclose the entire capacitor assembly in a plastic bag to prevent dust ingress. If you want to mount it outside then put the capacitor assembly inside an upside down plastic bucket and take the loop conductors up into this to keep everything waterproof.

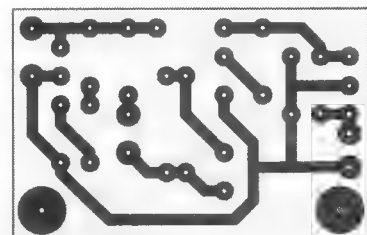
References

1. *An Overview of the Underestimated Magnetic Loop HF Antenna.* Leigh Turner VK5KLT, AR May 2009.
2. *ARRL Antenna Handbook.*
3. Discussions and emails with Leigh Turner VK5KLT.



LOOPSTEP Bottom Layer

Figure 6: The control electronics circuit diagram.



LOOPMTR Bottom Layer

Figure 5: The pattern for the meter PCB.